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CONSERVATION TILLAGE

FOR WHEAT IN THE GREAT PLAINS

U. S. DEPARTMENT OF AGRICULTURE
EXTENSION SERVICE

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Contents

Glossary

Conservation tillage is used in this publication to describe any soil management practice that leaves the soil surface resistant to erosion and conserves moisture. Some conservation tillage methods are: "minimum tillage," "no-tillage," "zero tillage," "reduced tillage," "stubble mulch," "chisel plant," and "till-plant."

Conventional tillage includes operations (usually plowing, disking, and harrowing) that control weeds and prepare a seedbed.

Minimum tillage is a general term that means limiting the number of cultural operations to those that are properly timed and essential to produce a crop and prevent soil damage. This implies the use of substitute techniques (including herbicides) for weed control or seedbed preparation.

No-till or **no-tillage** is a system in which a crop is planted directly into soil that has not been tilled since harvest of the previous crop. Other terms used to express the same type of system are "slit plant," "slot plant," "sod plant," or "zero tillage."

Stubble mulch or **mulch tillage** is preparation of the soil in such a way that plant residues are left to cover the surface both before and after plant growth is established.

Till-planting is a system in which sweeps or cultivators moving ahead of the planter cut a strip of soil through the vegetation, in a once-over operation.

Fallow period is the time between harvest of one crop and the planting of the next crop.

Summer fallow is a system of fallowing in which vegetative growth is restricted by cultivation or application of herbicide during the summer months to conserve soil water. This usually infers the omission of a crop during the summer growing season in semiarid areas.

Chemical fallow (or "ecofallow") is a cropping system designed to control weeds and conserve soil water by crop rotation, with a minimum disturbance of crop residues and soil. In this system, weed control is obtained by combining herbicides with subsurface tillage on fallow land. The protective cover of residues is easier to maintain with no-tillage or reduced tillage because each time the land is crossed with equipment, valuable residues are flattened or incorporated into the soil.

Conservation Tillage for Wheat in the Great Plains

C. R. Fenster[1], H. I. Owens[2], and R. H. Follett[3]

Why Use Conservation Tillage?

Both wind and water erode the soil of the Great Plains. The climate is variable and cyclic; wet periods of water erosion may be followed by dry years with serious wind erosion. Cultivation exposes the soil to further erosion.

For nearly 75 years, farmers have included summer fallow as part of their crop rotation systems in the Great Plains. But the early moldboard plows buried nearly all crop residue, exposing an almost bare fallow surface to water and wind erosion.

The plow that made settlement possible in the Great Plains contributed to the "dust bowl" that forced out-migration of farmers from that area in the 1930's. Those who remained learned to leave crop residues, such as wheat stubble, on fields to protect the soil against wind and water erosion. This "stubble mulching" let more rain and snow water soak into the soil for use by crops, and helped prevent gullies.

Plant residues also are a source of nutrients and improve soil tilth and physical properties. Removing residues may increase wheat yields temporarily, but long-term yields are comparable, or better, where residues are retained.

Conservation tillage is a relatively new concept in farming, designed to conserve these crop residues, increase soil water intake, reduce wind and water erosion, and save energy by reducing mechanical tillage. One system of conservation tillage is called "chemical

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Table 1—**Cropland Inventoried and Conservation Treatment Needs in 10 Great Plains States**[1]

Item	North Dakota	South Dakota	Nebraska	Kansas	Oklahoma	Texas
			(1,000 acres)			
Total cropland inventoried	27,501.5	18,619.5	20,014.2	29,623.8	12,992.6	35,630.3
Irrigated	43.1	170.7	3,269.5	1,603.3	503.9	8,348.6
Non-irrigated	27,458.4	18,448.8	16,744.7	28,020.5	12,488.7	27,281.7
Conservation treatment needs						
Total non-irrigated	14,670.5	9,655.4	11,649.0	17,584.1	4,896.5	14,989.1
Crop residues or annual cover crops	6,821.3	1,351.3	1,634.3	4,579.3	2,185.5	7,293.5
Sod in the rotation	1,183.6	3,255.0	514.0	110.0	10.9	192.8
Contouring only	810.8	993.0	162.2	632.7	241.2	229.8
Strip cropping, terraces and diversions	3,681.4	3,061.9	7,735.2	11,084.5	1,867.5	5,280.2
Permanent cover	740.7	528.1	1,021.2	850.4	422.2	1,117.1
Drainage	1,432.7	466.1	582.1	327.2	169.2	875.7
Total irrigated	42.9	141.6	2,031.1	1,153.9	310.2	5,892.7
Cultural or management measures only	24.9	28.6	256.8	133.8	49.2	917.8
Improved irrigation systems	8.4	80.3	1,026.2	808.2	156.2	3,663.4
Proper water management	9.6	32.7	748.1	211.9	104.8	1,311.5

[1] SOURCE: Compiled from state Conservation Needs Inventory (CNI) reports from **Basic Statistics-National Inventory of Soil and Water Conservation Needs,** 1967, USDA, Statistical Bulletin No. 461, 211 pages.

fallow" or "ecofallow." The most successful conservation tillage methods in the semiarid Great Plains combine the use of herbicides with mechanical tillage.

Compared with practices in conventional tillage, those used in conservation tillage systems should result in—

1. Equal or better weed control.
2. Equal conditions for germination, emergence, and crop stand.
3. Less compaction or puddling of soils.
4. Retention of more crop residues to conserve soil moisture and reduce wind and water erosion.
5. Equal or lower costs.
6. Equal or better crop yields.

There are good economic and ecological reasons to change from conventional tillage to conservation tillage in Great Plains wheat production.

The public is beginning to demand better control of wind and water erosion that cause pollution of air and sedimentation of streams. Their demands will probably increase, and regulatory laws for erosion control will be monitored and enforced by governments. Remote sensing data and on-site observations will detect infractions.

Conservation tillage can help Great Plains wheat farmers meet their own goals for profitable crop production along with minimal erosion. This system minimizes the length of time the soil surface is exposed without protective crop residues to buffer against erosion and moisture loss. It should also help stabilize crop production from year to year in spite of varied weather conditions.

Tillage methods can either damage or conserve soil. Wheat growers in the Great Plains sometimes perform from three to ten tillage

Montana	Wyoming	Colorado	New Mexico	10 State Total
		(1,000 acres)		
14,988.8	3,043.8	11,786.0	2,617.5	176,818.1
1,647.8	1,932.2	3,083.1	1,097.5	21,699.8
13,341.0	1,111.6	8,702.9	1,520.0	155,118.3
7,601.3	659.3	4,551.1	611.1	86,867.8
3,340.4	254.1	1,280.0	134.8	28,874.6
262.1	27.5	0.0	2.1	5,538.0
142.6	29.1	0.0	83.5	3,325.0
2,887.2	276.4	1,978.1	117.0	37,969.3
829.9	72.0	1,293.0	273.6	7,148.4
139.1	0.2	0.0	0.1	3,992.5
1,461.7	1,549.7	1,581.5	741.2	14,906.7
142.6	126.4	121.6	110.6	1,912.2
1,097.6	608.0	941.0	443.2	8,832.6
221.5	815.3	518.9	187.4	4,161.9

operations. Conservation tillage uses as few trips as possible over a field to control weeds and produce the crop. This reduces soil disturbance and compaction and leaves more protective plant residue on the soil. It also cuts time and energy costs.

Producing crops increases stress on prairie soils, but a cropping system using conservation tillage can be designed to reduce destructive effects. It should:

1. Minimize soil erosion, by wind or water.
2. Promote more efficient moisture storage in the soil.
3. Control weeds, insects, and diseases.
4. Provide seedbeds that insure good plant development.
5. Place seed firmly into moist soil for rapid germination and plant development.
6. Maintain permeable condition of the soil.
7. Maintain an adequate supply of plant nutrients.
8. Minimize the number of tillage operations.
9. Give yields as good as, or better than, other systems.
10. Earn a profit.

To be successful, conservation tillage must be planned specifically with regard to:

- Cropping systems used
- Expected rainfall
- Soil type
- Kinds of weeds present
- Energy needed to make the system work.

This publication is intended to assist the wheat producer or his technical advisors with such planning.

Research Shows Need

The success of no-tillage corn production in eastern and midwestern states has added impetus to research on conservation tillage for wheat.

Various forms of no-tillage for wheat have been tested by industry, the U.S. Department of Agriculture (USDA), and university researchers. At present, planting equipment, erratic weed control with herbicides, and the lack of adequate crop tolerance to herbicides are limiting factors. Research continues, with new herbicides and herbicide combinations. With the success of no-tillage corn, equipment companies now seem more interested in conservation tillage equipment for small grains.

A national inventory of conservation tillage needs was conducted by the U.S. Department of Agriculture in 1967. Table 1 presents conservation needs for the 10-state Great Plains region, taken from that study.

For the 10 Great Plains states, 56 percent of the nonirrigated, and 69 percent of the irrigated cropland was designated as needing some type of conservation treatment. One-fourth of all nonirrigated cropland in the 10-state area was judged to need strip cropping, terraces, or diversions. Approximately an additional one-fifth of the dryland cropland was judged to need crop residue and cover crop treatment. Subsequent change to more intense cropping may increase conservation treatment needs. The inventory, however, makes no distinction as to how badly the treatment is needed, how much erosion is now occurring without the practice, or the costs and benefits to be expected from initiating the practice.

Characteristics of the Great Plains

In planning to use a conservation tillage system for wheat production in the semiarid Great Plains, the climate and the fallow cropping systems used in the region become important considerations.

Climate

In the **northern Great Plains**, temperature and precipitation extremes are common. High wind velocities of short duration may occur in any month, but most prolonged windy periods occur in March, April, and May. High velocity winds erode soil that is fine and loose, when the soil surface is smooth, bare, and dry.

In the **central Great Plains**, the climate becomes progressively drier and cooler from east to west. This means annual precipitation here ranges from less than 12 inches to more than 32 inches. It is highly erratic—sometimes either double or less than half the long-term averages.

Figure 1. Area of Great Plains states with less than 20 inches of rainfall.

Adapted from Climatic Atlas, U.S. Department of Commerce, Environmental Service Administration, Environmental Data Service, 1968.

Rainfall in the **southern Great Plains** is usually characterized by pronounced summer maximum, but some regional differences occur in the distribution of monthly precipitation.

In the high plains of Oklahoma and Texas, the highest monthly precipitation occurs in May and June. Further east, a secondary increased precipitation may occur in September and October. Temperature as well as precipitation affects the water available for wheat production. In addition to the effect of latitude, a marked temperature difference occurs in the southern Great Plains because of a steep east-west gradient in elevation. As elevation increases from prairie to high plains, and temperatures become cooler, an inch of rainfall becomes more effective in crop production.

Fallowing

Low precipitation (less than 20 inches annually) is a dominant characteristic of the semiarid Great Plains (fig. 1). This limits wheat production. Fallowing is a method of coping with low precipitation. Farmers in the Great Plains use a fallow period in the cropping system to increase water available for succeeding crop growth. They forfeit production for one season in anticipation of at least partial compensation in increased wheat production the next season.

Fallow has been a controversial practice in some regions since its inception in the late 19th Century. Proponents have emphasized its water-conserving, weed-controlling, and crop-yield-stablizing virtues. Critics have emphasized the inefficiency in soil-water storage and erosion problems. Despite criticism, the acreage of fallow has steadily increased from 5 million acres in 1910 to 37 million acres west of the Mississippi River in 1967.

Fallowing programs usually fall into four categories:

1. **Bare fallow,** using a moldboard plow.
2. **Stubble fallow,** with heavy residues, using a one-way, offset, or tandem disk.
3. **Stubble-mulch fallow,** with medium to light residues, using chisel and subsurface tillage implements.
4. **Chemical fallow** using chemicals to control weeds and replace part or all of tillage operations.

Summer fallowing is being practiced primarily in semiarid areas (those receiving 20 inches or less of precipitation), although there are sizable acreages of fallow in areas with as much as 28 inches. Because of higher evaporation rates in the southern Great Plains, precipitation is less effective there than in the north. Water storage under fallow also decreases from north to south.

Further west and in the intermountain regions, a winter-type precipitation prevails. Precipitation falls during the cooler months, allowing more efficient soil-water storage than under summer rainfall conditions.

Crops and fallow are usually alternated in the drier regions, but with higher rainfall, other cropping sequences are followed. In some areas of the northern Great Plains, corn is often followed by 1 or 2 years of small grain, or fallow may be used in place of corn. In the central and southern Great Plains, a rotation of wheat-sorghum-fallow is often used.

According to the 1964 Census of Agriculture, the greatest concentrations of fallow for the 17 western states were in North Dakota, Kansas, and Montana, each with 6 to 7 million acres. Nebraska, Texas, Colorado, and Washington

each had 2 to 3 million acres. South Dakota, California, Oklahoma, Oregon, and Idaho each had about 1 to 1-1/2 million acres. Each of the remaining states had about one-third million. Since the acreage of fallow has increased, farmers apparently have felt that fallow is worthwhile, at least for immediate benefits.

Summer fallowing increases soil-water storage. However it is a very inefficient method of storing soil water. In the northern Great Plains, an average of only 19 percent of the precipitation received during the 21-month fallow period for spring wheat is stored in the soil. In annual cropping of spring wheat, an average of 32 percent of the precipitation received during the 9 months from harvest to seeding is stored. If water storage efficiencies could be increased to more than 50 percent from harvest to seeding time in an annual cropping system, then as much water could be stored in the soil at seeding time as during the 21-month fallow period. Reaching this level of efficiency is not beyond the realm of possibility. However, the saving in energy costs and water may favor producing one higher-yielding crop every 2 years instead of annual cropping.

Wind erosion may be severe on fallow in the alternate fallow and spring wheat system commonly used in the northern Great Plains. Stubble-mulch tillage has helped reduce the problem, but usually by the second winter of the fallow period, insufficient crop residue remains to control erosion. Strip cropping and barriers of trees, grass, sunflowers, corn, and flax are used to reduce wind erosion.

Winter wheat is vulnerable to wind erosion in March and April. It produces more straw than spring wheat. In a wheat-fallow system more straw is left at the end of the 14-month fallow period.

In the Great Plains, wind erosion occurs primarily after the wheat has been planted or during the dormant period. Bare fallow land has more than 60 percent greater erodibility than land with a protective cover of residues. Use of modern subsurface tillage equipment and drills capable of planting in residues, reduces wind erosion in the Great Plains. However, weeds may require more tillage operations.

Water erosion is a problem on fallow lands in nearly all regions. Both snow melt and torrential rains cause erosion. Snow is normally blown away from fallow fields, but runoff from snow collected in adjacent stubble fields or in barriers often moves across fallow fields and erodes them. Snow melt on frozen soil increases erosion.

Saline seeps develop in the alternate crop-fallow system widely practiced in Montana and North Dakota. Saline seep areas which have developed on some hillsides, gentle slopes, and drainageways are a serious problem.

Farmers are greatly concerned about these seep spots. Removing the affected land from cultivation makes the surrounding area more difficult to farm. Furthermore, once a seep spot develops, it expands rapidly and may cover several acres. Such seep spots are appearing in cultivated fields of north central and northeastern Montana, western North Dakota, and other areas of the northern Great Plains states and southern Canada. The problem stems from the geology of the region, the farming practices, and surplus water moving through the soil profile.

Studies indicate that using the water for crop growth before it penetrates beyond the root zone may help solve the problem of saline

seeps. This requires annual cropping, or at least more intensive cropping, and limited use of fallow. Establishing perennial grasses or planting a deep-rooted crop such as alfalfa may help control the development of saline seep areas. However, these crops should be fertilized to encourage deep rooting.

Influence on Wheat Yields: Wheat yields are usually higher after summer fallow than in other cropping systems, but it takes 2 years to produce one crop with the fallow-crop system.

In table 2, at the Bushland, Texas-Southwestern Great Plains Research Center, the continuous wheat and wheat-fallow systems involved two types of tillage: plowing with a one-way disk plow and subsurface tillage. The average yield combining all tillage methods was 15 bushels per acre for wheat-fallow and 9.6 bushels per acre for continuous wheat. The yield increase due to the fallowing, compared with continuous cropping was, therefore, 56 percent. This was less than the 100 percent yield increase needed for a given acreage farmed in the wheat-fallow system to produce as much as that acreage continuously cropped. Wheat yields are usually higher under stubble-mulch systems than with bare fallow in semiarid regions. Where annual precipitation is above 20 inches per year, weeds are difficult to control and may reduce wheat yields under stubble-mulch systems.

On the other hand, a less than 100 percent yield increase from using fallow still is justified economically. Yield increases exceeding 100 percent from using fallow have been reported from western Kansas and Nebraska and approaching 200 percent in northeastern Colorado (table 2). This indicates that summer fallowing to increase yields in the high plains of Texas and Oklahoma is relatively inefficient compared with summer fallowing in the central Great Plains. Summer fallowing is not efficient in storing water, but raising wheat may not be feasible in the driest part of the high plains much of the time, except by summer fallowing.

Table 3 compares effects of three tillage methods on wheat yields under both fallowing and continuous cropping systems. Most of the yields from one-way disk plowing are intermediate between those from stubble-mulch tillage and those from moldboard plowing. Outside of the two locations in the Pacific Northwest, the yield differences were slight between mulch tillage and moldboard plowing.

Table 2—**Comparison of yields from wheat-fallow and continuous wheat systems***

Cropping System	Location	Wheat Yields (Bushels Per Acre)	Annual Average Precipitation 1931–60 (Inches)
Wheat-Fallow	Moccasin, Montana (9 yr. av.)	32.0	13.7
Wheat-Barley-Fallow	Moccasin, Montana (9 yr. av.)	39.0	
Wheat-Fallow	Akron, Colorado (60 yr. av.)	21.7	16.8
Continuous Wheat	Akron, Colorado (60 yr. av.)	7.4	
Wheat-Fallow	Colby, Kansas (49 yr. av.)	19.6	17.9
Continuous Wheat	Colby, Kansas (49 yr. av.)	9.3	
Wheat-Fallow	North Platte, Nebraska (56 yr. av.)	31.1	17.5
Continuous Wheat	North Platte, Nebraska (56 yr. av.)	12.4	
Wheat-Fallow	Alliance, Nebraska (23 yr. av.)	18.3	16.3
Continuous Wheat	Alliance, Nebraska (23 yr. av.)	7.4	
Wheat-Fallow	Bushland, Texas (29 yr. av.)	15.0	19.7
Continuous Wheat	Bushland, Texas (29 yr. av.)	9.6	

*Adapted from ARS-USDA Conservation Research Report No. 17, 1974.

Table 3—**Summary of average annual yields of wheat under various tillage methods at 15 experimental locations**

	Annual Average Precipitation 1931–60	Period	Yield of wheat following fallow or in rotation			Yield of continuous wheat		
	Inches	Years	Bushels Per Acre			Bushels Per Acre		
			Mulched	Plowed	Onewayed	Mulched	Plowed	Onewayed
Akron, CO	16.8	12	23.2	23.1	----	----	----	----
St. Anthony, ID	10.9	14	25.2	23.5	23.9	----	----	----
Hays, KS	22.9	11	----	----	----	19.4	20.5	20.6
Froid, MT	12.8	11	25.9	27.5	26.1	----	----	----
Havre, MT	11.3	12	17.4	17.1	16.6	----	----	----
Moccasin, MT	13.7	5	----	----	----	21.2	22.0	----
Lincoln, NE	26.8	16	25.2	26.9	----	----	----	----
North Platte, NE	17.5	4	26.6	25.1	26.6	16.8	15.6	15.1
Mandan ND	16.3	22	16.3	17.5	----	----	----	----
Cherokee, OK	25.6	10	----	----	----	14.4	19.3	----
Stillwater, OK	32.2	12	21.8	21.6	21.0	----	----	----
Pendleton, OR	13.0	13	31.0	36.1	30.2	----	----	----
Newell, SD	15.2	22	20.1	19.7	----	----	----	----
Amarillo, TX	19.7	11	18.3	----	16.0	11.0	----	9.6
Pullman, WA	20.5	10	28.9	34.6	----	----	----	----

Compiled from Technical Bulletin No. 1166, U.S. Department of Agriculture Experiment Stations.

Managing for Conservation Tillage

The primary purposes of tillage are to control weeds, reduce wind and water erosion, increase water storage and nutrient release through fallow, and to prepare a firm, mellow seedbed. Conservation tillage operations leave part of the crop residue on top of the soil to reduce erosion during the non-growing season.

Tillage also breaks hardpans, reduces density, increases aeration and improves water infiltration. But too much tillage can also cause adverse soil conditions.

Plan the conservation tillage management program to retain sufficient protective residue, yet avoid unnecessary overhead costs. Excessive use of machinery and energy, and unnecessary tillage operations increase costs.

Since crop production in the northern Great Plains is limited mostly by lack of water, the tillage practiced for seedbed preparation in this region should conserve or store as much water as possible for the succeeding crop. However, poorly drained soils sometimes do need tillage to eliminate surface water and facilitate early spring seeding. Yield reductions due to late seeding because of excess water can be as great or greater than those due to reduced water supply.

Better grain yields resulting from conservation tillage that controls erosion and increases water storage may be offset by diseases and low early-season soil temperatures.

We know that eliminating weeds saves water, but we do not know the growth stage and density at which weeds consume more water than is lost by tillage. Farmers too often base tillage schedules for weed control on convenience and not necessarily on the best timing for water conservation.

The effects of tillage practices, including residue management, on water storage and erosion have been more extensively evaluated on fallow than on continuously cropped soils in the northern Great Plains.

Recent changes in wheat prices and in acreage restriction policy have created more interest in continuous cropping, while fallow acreage is reduced. Because of these changes, the farmer is under greater pressure to complete spring seeding as early as possible to obtain maximum production. Therefore, fall tillage of stubble for spring planting has increased. The period of acreage restriction was accompanied by an increase in tractor power and tillage equipment size. This led to more frequent tillage and deeper fall tillage.

Plans for tillage operations should include the following considerations:

1. **Soil cloddiness** to maintain particle sizes greater than .84 mm (.033 inch) in diameter for wind erosion control.
2. **Surface roughness** to reduce wind velocities at the soil surface and retard water runoff.
3. **Residue maintenance** to maintain a protective cover of residue on the soil surface during the fallow period and after seeding for erosion control.
4. **Conservation** of soil moisture.
5. **Development of a firm, mellow seedbed**—firm enough to retain moisture, yet mellow for good root penetration.

Selecting Tillage Equipment

The initial tillage operations for mulch fallow require a different set of tillage equipment from that used for bare fallow. Several types of tillage implements may be required.

The kind, quality, quantity, and state of decomposition of residues; kinds of weeds; moisture condition; soil texture; length of fallow; and time of operation should be considered when selecting tillage equipment.

In choosing tillage machine systems for summer fallowing or conservation tillage, the operator must consider:

1. The net return on investment, considering machines available; energy, labor, and fertilizer requirements; weeds, and crop yield.
2. The equipment's effect on erosion and moisture conservation.

Tillage implements—depending on type, adjustment, and speed of operation—reduce varying amounts of surface residue. As travel speed increases above 4 miles per hour, more residue is buried, except when blade or sweep-type machines are used.

Speeds of 4 miles per hour or more are needed to improve weed control. Additionally, with faster speeds of tillage operations, more power is required, more fuel is consumed, and wear and tear on equipment increases.

Stirring or Mixing Implements

Disk-type implements greatly reduce the amount of residue in any one operation. Increases in disk size, concavity, spacings, and depth of operation, all result in increased amount of residue covered. Disk-type implements give good control of grassy weeds if operated at shallow depths, and are very good in reduction of extremely heavy residues. An offset or tandem disk pulverizes soil more than a oneway disk.

Chisel plow implements are equipped with high clearance shanks and are spaced to function in heavy residues. The amount of residue saved increases with increasing stubble height. For maximum weed control, a rotary rod can be used behind the last row of shanks. The combination of chisels and rod leaves the soil surface level. This tends to reduce surface evaporation. A second advantage of the rod attachment is that more of the residue is lifted back to the soil surface.

Field cultivators are usually not as sturdy as chisel plows, although they have the same general design. The tillage points may be single or double pointed shovels, spikes or small sweeps. The shanks are usually spaced 8 to 10 inches apart with less clearance than a chisel plow. They are effective for controlling small weeds, for breaking soil crust, and excellent for surface roughening.

Mulch treaders are used as a secondary tillage tool to improve weed control after initial tillage, especially when weeds are shallowly rooted. They can also be used to distribute and anchor heavy residues or to firm a seedbed. They also tend to pulverize the soil.

Subsurface Implements

Subsurface sweeps, rodweeders with semichisels, and plain rotary rodweeders are the most effective tillage implements for conservation of plant residues on the soil surface. Sweeps range in size from 20 inches to 5 or 6 feet in width. The blade itself ranges from 6 to 8 inches in width, and the V-blade angles vary from 60 to 100 degrees. Wide-angle blades penetrate the soil more easily, but they shed weed roots and residues less easily than smaller-angle blades. The usual blade pitch is about 37 degrees for optimum soil lift and weed control. Rolling coulters at least 20 inches in diameter are desirable for cutting heavy residues and weeds.

A rodweeder equipped with semichisels will penetrate firm soil and can be used as an initial or secondary tillage tool. It causes more stirring action than does a sweep machine. This improves weed control over a plain rod, but destroys more residues and is more subject to plugging in heavy residues than a sweep.

Plain rotary rodweeders are used only for secondary tillage operations, because they control small weeds and firm the seedbed prior to seeding. The major disadvantage of all subsurface tillage tools is that weed control is not as good as with the stirring machines.

The farm or ranch operator has a choice of many different machine systems. Energy requirements for moldboard plowing are high compared to other methods of initial tillage, and the resulting surface, lacking residue, is highly susceptible to erosion. Table 4 compares these implements and the amounts of energy they use.

Table 4—**Types of tillage implements: The amounts of residue remaining and energy used**

Implement	Surface residue remaining after tillage	Speed	Type of Tillage	Energy* Requirement PTO	Consumption Gasoline†	Consumption Diesel††
	Percent	**Mph**		**Hp hr/A**	**Gallons/A**	
Moldboard Plow (7" deep)	0–5	4	Primary	23.4	2.6	1.8
Chisel Plow 2" wide points (7" deep)	75	4	Primary	18.9	2.1	1.5
Oneway (18" to 20" disks)	60	4	Primary Secondary	10.0 13.6	1.1 1.5	0.8 1.0
Oneway (24" to 26" disks)	50	4	Primary Secondary	12.5 15.4	1.4 1.7	1.0 1.2
Heavy Tandem or Offset Disks	60 50	4	Primary Secondary	10.7 14.5	1.2 1.6	0.8 1.1
Field Cultivator (12" to 18") Sweeps	80	4	Primary Secondary	5.3 7.3	0.6 0.8	0.4 0.6
V-Sweep (20" to 30" wide)	85	6	Primary Secondary	8.0 10.9	0.9 1.2	0.6 0.8
V-Sweep (over 30" wide)	90	6	Primary Secondary	9.3 12.7	1.0 1.4	0.7 1.0
Mulcher Treader (spade tooth)	75–80	6	Secondary	4.0	0.4	0.3
Rodweeder (with semi-point chisel or shovel)	85	5	Secondary	8.5	0.9	0.7
Rodweeder (plain rotary rod)	90–95	5	Secondary	6.9	0.8	0.5

* Tractive Efficiency Factor included.
† 9 hp hr/gallon.
†† 13 hp hr/gallon.
Compiled from EC-703, Cooperative Extension Service, South Dakota State University, 1975.

To choose equipment and sequence of operation, you must know the amount of residue on the soil surface before fallow tillage begins, and how much residue is required at seeding time to protect the soil. Residue present before initial tillage can be estimated from the straw-grain ratio. (Remember the "rule-of-thumb" that usually 100 pounds of straw is produced for each bushel of wheat harvested.)

The amount of residue needed for soil protection at seeding time depends on the soil texture (Table 5).

V-blade performing subsurface tillage. Blades are 72 inches wide in four sections. About 90 percent of wheat residue remains on surface after one tillage operation.

Table 5.—**Relationship of texture and the amount of plant residue needed for erosion control at wheat seeding** *

Soil Texture	Minimum amount of residue in pounds per acre
Sandy to sandy loam	1,700
Very fine sandy loam to silt loam	1,200
Silty clay loam	1,000
Clay loams	750

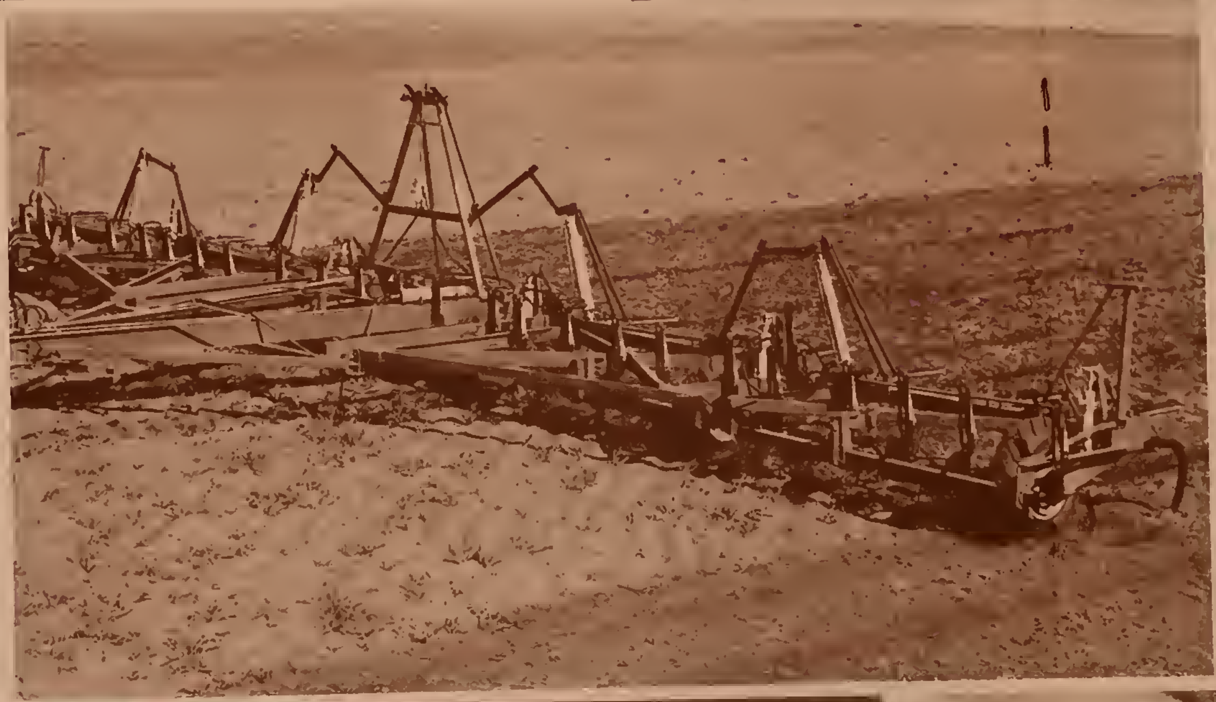
* Other factors to consider include: climate, wind direction, and field width.

Each tillage operation decreases the amount of plant residue remaining on the soil surface.

Tillage Sequence

No one set of tools is best for all conditions. Combinations of sweeps, disks, and rodweeders will be needed for particular situations. Choice of machines and tillage sequence is based on the amount of plant residue present at the beginning of fallow, the amount of residue needed at seeding time (table 5), and the weed situation.

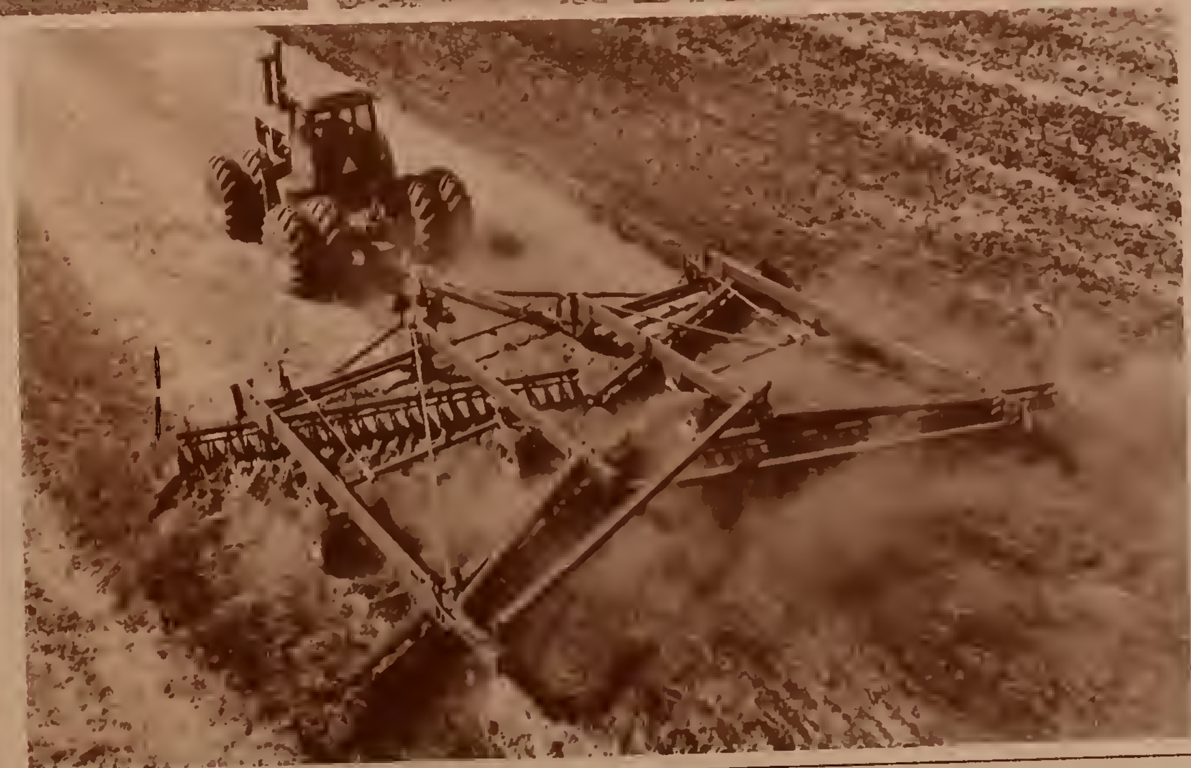
If residues after harvest are light (less than 2,000 pounds per acre) sweep machines or rodweeders with semichisels should be used for all tillage operations except the last one, which should be done with a plain rotary rodweeder.



Rodweeder, a subsurface implement, is used to control weeds and firm the seedbed.

Chisel plow equipped with 16-inch sweeps spaced 12 inches apart. Approximately 1800 pounds per acre of residues remain on the soil surface.

Mulch hoe drill seeding winter wheat in approximately 1500 pounds per acre of wheat residues. V-press wheel presses the soil firmly over seed.



Disk reduces the amount of wheat residue. It controls grassy weeds if operated at shallow depths.

Approximately 1600 pounds per acre of wheat residue after fallowing. This will provide excellent wind erosion control.

Approximately 2670 pounds per acre of wheat residue after fallow and before planting wheat. Fallow operations included four V-sweep and one rodweeder.

Approximately 2500 pounds per acre of wheat residue after fallow and before planting wheat. Excellent for erosion control.

Approximately 2950 pounds per acre of wheat residue in April. Residues remained standing over winter to catch snow. Land will be tilled as necessary to control weeds during the fallow period.

If the residues are medium (2,000 to 4,000 pounds per acre), the oneway, tandem, or offset disks can be used as a first operation, followed by subsurface tillage equipment such as a sweep, or a rodweeder with semichisels. The last operations should be done with a plain rotary rodweeder for seedbed firming and weed control.

If residues are extremely heavy (4,000 to 6,000 pounds per acre), the disk-type implements are best used for several operations, followed by a chisel or sweep and finally the rodweeder. Disk-type equipment has an advantage in a wet spring when grassy weeds such as downy brome and volunteer wheat are a problem.

The following examples show how to determine the type of tillage and sequence for producing winter wheat:

Situation No. 1—There are few weeds in the stubble after harvest, and medium straw (2,000 to 3,000 pounds per acre). Fallowing operations need not begin until spring. Delay the first operation until weeds and volunteer wheat have started growing. Machines equipped with sweeps 30 inches or more wide are best for the initial tillage. Till to a depth of about 4 to 5 inches. Use a rodweeder with chisels for secondary tillage. One or more rodweedings may be needed to control weeds.

Before seeding winter wheat, do the final tillage with a plain rodweeder. This tends to kill the small weeds; including downy brome, and firms the soil, providing an improved seedbed.

Situation No. 2—There is much weed growth in the stubble, especially downy brome and volunteer wheat, with medium straw (2,000 to 3,000 pounds per acre). Weed kill is essential, but the equipment used should leave the stubble standing to prevent loss of snow cover. Use a medium to wide sweep and till 4 to 5 inches deep so that weed roots are cut and the stubble stands. Time the operation so that the weeds are killed before they go to seed. Frequently two operations, one after harvest and one before "freeze up", are needed to control fall weeds. In the spring, follow the procedure outlined for Situation No. 1.

Situation No. 3—There is heavy straw (more than 4,000 pounds per acre), with no fall tillage. The first operation may be with a oneway or tandem disk. Till at a shallow depth to save as much straw as possible. Set the oneway at a narrow cut, so that the disks will not need to go deep in order to cut the soil and kill volunteer wheat and weeds. It is best to do this operation when the soil is dry, to get maximum weed kill. Sometimes excessive straw in low areas may necessitate the use of stirring or mixing tools for several operations only on those parts of the field.

When weeds start again, one of several implements may be used. An implement that undercuts the soil and loosens it to a depth of about 4 to 5 inches is desirable. Chisel plows, sweeps or rodweeders with shovels are recommended. After several operations, the rodweeder should be used to finish seedbed preparations.

Timing Tillage

Remember that the objective of summer fallow is to save water by killing weeds, while maintaining residues for soil protection. Weeds must be controlled to conserve moisture. However, tillage operations cause soil moisture loss. If there are only a few weeds in the stubble at wheat harvest, the stubble is usually left until spring. Tillage should be performed immediately, however, if weeds are beginning to set seed, or if weeds enhance diseases, such as wheat streak mosaic.

Weeds are easiest to kill on the first tillage trip. Poor weed control early in the fallow sequence results in the development of a dense weed root system near the soil surface. This makes it more difficult to control weeds throughout the season. Experiences have shown that an early spring tillage followed by a second in about 2 weeks is needed to obtain a good kill on grassy weeds. The second tillage kills the weeds that are missed the first time. Weeds such as downy brome

must be controlled before they set seed. For instance, this is about May 10 for western Nebraska and 2 weeks earlier for the remainder of the state.

The soil should be fairly dry so that weeds will wilt within 30 minutes after tillage. If it is too wet, weed control will be poor and tillage layers may develop in the soil.

Tips on Tillage

Soil tilth. Too much tillage destroys residue, pulverizes and drys out the topsoil, and decreases the benefits of fallowing. Tillage at the same depth year after year results in a layer of compacted soil immediately below the sweep depth, especially when the soil is wet. Varying the tillage depth, or occasionally using a chisel-type machine, helps keep the soil in good tilth. The deepest tillage operations should be early in the fallow season so that a firm seedbed can be developed before seeding. Tillage deeper than 6 inches is not beneficial under semiarid conditions.

Combine straw spreaders. Large windrows or piles of straw cause difficulty during tillage, and seeding of the following crop. Straw choppers or good straw spreaders are essential for uniform distribution of the residue.

Residue distribution. If residues are exceedingly heavy or bunched before drilling, mulch treading will distribute and anchor the residues in the soil. Rotary hoeing at fairly high rates of speed when the residues are dry will break them up and distribute them more uniformly. When possible, heavy residues should be spread uniformly early in the fallow season. Working fields diagonally will also aid in distributing residue and leveling the soil.

Seedbed condition. Tillage operations during fallow often alter soil structure. For example, a cloddy surface (aggregates greater than .84mm in diameter) is desirable for increasing water intake and to prevent wind erosion.

The goal should be to plant the seed about 1 inch deep in firm, moist soil. Soil aggregates should be fine enough to provide good soil-seed contact, but not so fine that rain will puddle the soil and cause crusting, or so fine that wind will drift the soil. Proper use of a plain rodweeder—

- Reduces clod size
- Firms the seedbed
- Provides late weed control
- Preserves residues for erosion control.

Till at shallow depths during late tillage operation to preserve as much surface moisture as possible.

Timing Planting

Timing of the planting date of winter wheat is important in conserving moisture and controlling diseases and insects. Planting either too early or too late cuts yields. The optimum planting date gives time for the wheat plant to get well established, without serious loss of soil water or exposure to disease. The top growth of the plant supplements the effects of vegetative residues in controlling wind and water erosion. Planting too early will produce excessive top growth, which uses valuable stored fallow moisture in unproductive fall growth. Early planted wheat is more susceptible to crown and root rot and to wheat streak mosaic virus.

On the other hand, delaying planting of winter wheat too long may prevent plants from becoming well established and leave them more subject to winter kill. Late planting may not produce enough growth to control wind erosion.

Spring wheat in the Great Plains usually produces the highest yields when planted as early as soil conditions permit. Normally spring wheat is planted in late March or early April. Heat and moisture stress is likely to occur during July, which reduces yields on late-planted wheat.

Planting Equipment

A seedbed should be firm enough to provide good seed-soil contact and moist enough for germination and seedling establishment. Consider soil moisture and the amount of residue present at seeding time when selecting planting equipment.

The best drills are adaptable to a range of moisture and mulch conditions. A drill that will plant through a dry soil layer or crop residue

mulch and place the seed into moist soil is essential. Seeds can germinate quickly in moist soil to establish the stand near the optimum date. In drier areas, expect greater thickness of dry soil than in the wetter climates; a different drill may be required.

Types of drills commonly used for seeding winter wheat are:

1. **Surface drills**—usually single disk (may be double disk) drills with row spacing of 6 to 8 inches.
2. **Semideep furrow drills**—usually single disks or small hoes spaced 8 to 10 inches apart.
3. **Mulch hoe drills**—usually hoes or shoes spaced 12 to 14 inches apart (may be large disks).

Surface drills with disk openers are used where no residues—or small amounts of residues—are on the soil surface at seeding time. Disk opener drills are commonly used in the continuous wheat producing areas where the plow is the primary implement for preparing seedbeds. Disk openers are also used by growers who practice bare fallow methods where few or no residues are on the soil surface at seeding time. Semideep and mulch hoe drills are used for one or more of the following reasons:

1. Planting in furrows enables the grower to seed through a much thicker layer of dry soil than is possible with a disk drill. This is especially advantageous in drier areas.
2. Planting in furrows provides a rough soil surface, which aids in wind erosion control.
3. Planting in furrows with a hoe opener permits the grower to plant in the mulched soils that result from stubble mulching tillage practices. This planting technique preserves the maximum amount of surface residues and anchors them securely for maximum wind erosion control. Furrow drills with large disks may also be used to plant in mulched soils. Wheat drilled in furrows is better protected against winter kill.

When selecting drills for seeding in mulched residues, consider the following specifications:

1. Allow at least 18 inches of vertical clearance between the tip of the hoe and the attachment of the hoe to the frame of the planter.
2. Allow at least 20 inches of clearance between ranks of openers.
3. Space rows 10 to 14 inches apart.
4. Use shoe or hoe opener width of not more than 4 inches.
5. Use press wheels that pack the soil firmly and anchor residues in the ridge. Enclosed convex press wheels have proved very satisfactory. Flexibility is necessary with any of the three types of drills if they are to be used on fields where the surface is irregular. Drills that flex in 6- to 8-foot sections are desirable, especially on terraced land.

Planting Depth

The depth of soil over the seed is very important. Seed must be placed firmly in moist soil and covered with sufficient soil to prevent rapid drying. Depth of soil over the seed should be 1 to 2 inches in medium-to-fine textured soils, and 2 to 3 inches for coarse. Never cover seed more than 4 inches. Wheat seeds covered with more than 4 inches of soil definitely lose seedling vigor. They often fail to emerge or, if they do, they are more susceptible to winter kill and disease. Mulch hoe drills or semideep furrow drills are advisable in areas where the surface soil may be dry at planting. They allow placing the seed deeper in the soil without excessive soil covering the seed.

Preventing Erosion

Keeping a protective cover of residues on the soil surface is the simplest and surest way to control both water and wind erosion.

Conserving Water

Mulching soil with plant residues increases water infiltration into the soil and reduces water erosion. In the Great Plains, more water is stored in the soil as the amount of residues on the surface of fallow land is increased. Infiltration is maintained at a higher rate for a longer time than with bare fallow.

However, **yields are usually better with stubble-mulch fallow in dry years and with bare fallow in wet years.** In the more humid regions, yield **reductions** are frequently observed with stubble mulching compared to bare fallow. The yield reductions are due to factors such as lower soil temperatures, poor weed control, and lower nitrogen availability because of lower nitrate production.

Stubble left upright over winter is very important to snow catchment and water conservation in much of the Great Plains. According to Greb, Black and Smika, snow melt moisture is more than 66 percent effective, compared with 0 to 15 percent effectiveness of moisture from a July rainstorm.

Unger and Parker studied the effectiveness of stubble-mulch farming on water conservation during the fallow period. They found that mulches conserved water during long dry periods. Evaporation from soil over a 16-week period was reduced 57 percent by straw applied and mixed with the soil surface, and 19 percent by straw buried 1.17 inches deep. Other findings in Nebraska, Colorado, and Montana showed a significant increase in fallow moisture efficiency with 1,500 to 6,000 pounds per acre of surface straw mulch, compared with bare fallow.

Barnes and Bohmont in Wyomimg found that the water intake at the end of one hour was 0.3 inches for bare fallow, 1.20 inches for grassland, and 2.26 inches for stubble-mulch.

McCalla, emphasizing the importance of mulches on soil structure, showed that a surface mulch is more important than soil organic matter in increasing water infiltration. A subsoil devoid of organic matter and not mulched had an intake of 0.44 inches per hour, while the mulched subsoil infiltration rate was 0.76 inches per hour for the same period of sprinkling. Infiltration in a good topsoil was 0.55 inches for nonmulched, and 1.62 inches for mulched, after 3 hours of sprinkling.

At Alliance, Nebraska, stubble-mulch fallow was compared to bare fallow in a wheat-fallow rotation on a Keith, very fine sandy loam soil with a 4 percent slope. Soil loss (table 6) was reduced 86 percent, and runoff 60 percent when compared to bare fallow. In growing wheat, soil loss was reduced 75 percent and runoff 43 percent by using stubble-mulch fallow. The effectiveness of stubble-mulch farming for conserving water during both fallow and the growing season is significant.

Table 6—**Runoff and soil loss produced in wheat-fallow rotation at Alliance, Nebraska from 1958 to 1965**

	During fallow period		During growing period	
	Stubble mulch	Bare	Stubble mulch	Bare
Runoff (inches of water)	1.9	4.7	4.5	7.5
Soil loss (pounds per acre)	3,400	21,900	8,900	34,900

Preventing Wind Erosion

Mulching soil with plant residues curtails wind erosion, reducing air pollution.

An 8-year study was conducted in western Nebraska to evaluate the effects of stubble mulching, oneway disking fallow, and bare fallow, on wind erodibility in a wheat-fallow rotation. Over the 8-year period wind erosion amounted to 0.86 tons of soil per acre for the stubble-mulch tillage, 1.4 for oneway fallow, and 2.94 for bare fallow. During 2 years out of 8, soil losses from plowed plots amounted to 5.7 and 10.1 tons per acre, thus exceeding the 5 tons per acre generally accepted as a tolerable limit. In no year did the soil loss from oneway disk or stubble-mulch fallow exceed that limit.

In wind tunnel tests on winter wheat fields in the Nebraska panhandle, fields bare fallowed with the moldboard plow had an average erosion loss of 10.7 tons per acre, compared to only 0.8 tons per acre for stubble-mulch fallow fields. The reduced erodibility on the stubble-mulched areas was due to the larger amounts of surface residue (2,620 pounds per acre), compared to smaller (610 pounds per acre) amounts on clean tillage. Data show the advantages of subsurface tillage implements over soil-inverting implements for controlling wind erosion. However, during dry years, initial residues may be so sparse that even where subsurface tillage implements are used to provide adequate weed control, residue quantities will be insufficient to protect succeeding crops from wind erosion.

Weed Control

Since weeds compete with crops for moisture, light, and nutrients, wheat yields depend on successful weed control. The producer planning to use a conservation tillage system should consider:

- A cropping system adapted to weed control
- Kinds of weeds—perennial or annual
- Use of the right combination of herbicides and tillage methods to control problem weeds
- Soil texture and topography.

Some weeds cannot be controlled effectively when heavy crop residues remain on the soil surface, therefore, **practices used in conservation tillage may not provide the best soil surface conditions for controlling weeds with herbicides.**

In the **chemical fallow** cropping system, weed control is obtained by combining herbicides and subsurface tillage on fallow land.

Wicks and Smika at North Platte, Nebraska, using a wheat-fallow rotation during a 6-year period (1963–69), compared no-tillage *with herbicides* to conventional tillage. The plots receiving no-tillage (weeds controlled by herbicides) had the least weed growth, the most soil water stored, and the highest amount of surface mulch retained. They also had the highest grain yield of all fallow treatments. The bare fallow treatment yielded 40 bushels per acre, stubble-mulch fallow yielded 42.8, and the no-till fallow yielded 47. At Sidney, Nebraska, with a wheat-fallow rotation during a 6-year period (1969–75), bare fallow yielded 34.1 bushels per acre; stubble-mulch fallow 33.5; and no-till, 35.6.

Kinds of Weeds

Perennial weeds that cannot be controlled in growing crops are **milkweed, Texas blueweed,** and **swamp smartweed.** Conservation tillage practices can increase infestation by these weeds in row crops. Wheat production using intensive tillage from harvest to planting may help control these weeds.

Using 2,4-D can help control **field bindweed** or **bur ragweed** during the crop production year for corn, grain sorghum, and winter wheat. If 2,4-D is properly applied to corn or sorghum (after dough stage) for 2 consecutive years, it will help control **dogbane.** Then the field can be planted to wheat.

Change in the cropping sequence can help reduce **annual weeds. Winter annual weeds** (broadleaved and grasses) are problems in winter wheat. Infestations of winter

annual grasses such as downy brome, cheat, jointed goatgrass, or volunteer wheat, can be reduced by planting infested fields (after spring tillage) to spring row crops such as sorghum or millet for at least 2 years.

Planting wheat during the latter part of the recommended planting period will allow for an additional tillage operation. This often reduces the infestation of winter annual grasses. However, adequate soil moisture is essential to obtain early germination and partial control of these winter annual grasses prior to wheat planting.

Weeds such as **downy brome** and **volunteer wheat** would be easier to control if more effective herbicides were available. These weeds begin growing in late fall or early spring. Downy brome sets seeds during early May. When the spring season is late or wet, it is difficult to control grassy weeds before they set seed, especially with sweep equipment.

Summer annual weeds such as **foxtails, wild oats,** and **pigweed** are problems in summer crops such as sorghum, corn, or millet. These weeds can be reduced by cropping with wheat or wheat-fallow for several years.

Kinds of Herbicides

Preemergence herbicides are applied at or after planting, but before the emergence of specified weeds or crops. The best conditions for effectiveness of preemergence herbicides are:

- A well-prepared seedbed with residue thoroughly incorporated into the soil prior to planting and herbicide application.
- A $1/2$ to $2/3$-inch rain received within 3 to 8 days after herbicide application. This helps activate the herbicide.
- A very shallow incorporation of herbicide into the soil by rotary hoe or similar machine, to help activate the herbicide if no rain is received within 3 to 8 days after application of herbicide.

Postemergence herbicides are applied after emergence of the specified weed or planted crop. The best conditions for effectiveness of postemergence herbicides are when—

- Weeds are at the growth stage recommended for treatment, and growing rapidly.
- Herbicides are applied broadcast only at the recommended stages of crop growth as directed on the label.
- Weed leaf surfaces are thoroughly covered.
- A wetting agent, if recommended, is used to increase retention of herbicides on leaf surfaces.

Using Herbicides

Successful herbicide combinations are now available for producing wheat under conservation tillage systems. In Nebraska and Kansas, combinations of herbicides applied after wheat harvest in wheat-fallow-wheat or wheat-sorghum-fallow or wheat-corn-fallow systems controlled weeds. Contact herbicides in chemical fallow programs have been used successfully to control annual bromes and volunteer wheat. This practice has not been widely accepted by growers because of costs, even in areas of limited moisture.

Probably several herbicide combinations will be used in conservation tillage for wheat, depending on weed species, weed population, soil type, tillage system (fallow, no-tillage, etc.), available soil water, and crop tolerance. Herbicide applications may be combined with specific tillage operations into a conservation tillage system to reduce, but not eliminate, the number of operations.

Proper use of specific herbicides has little or no adverse effect on desirable non-target plants. But planning for use of herbicides should include:

- Identifying problem weeds.
- Selecting an herbicide (registered for use with the intended crop) that can effectively control problem weeds, but will not persist and injure the succeeding crop.
- Applying herbicide as directed on the label for the current stage of weed and crop growth and soil condition.
- Using low spray pressure (usually 25 to 30 pounds per square inch) to reduce loss of herbicide and hazard of injury to desirable plants from herbicide drift.
- Using calibrated equipment correctly, to

apply herbicide at recommended rate in recommended spray volume (usually 20 to 40 gallons per acre).

- Reading and following all directions, warnings, and precautions on the herbicide label.

Special Weed Control Problems

1. **Problem situation:** Need to control emerged weeds prior to planting a crop, when residues of a previous crop are present on the soil surface.
   Solutions:
   - Select and use an effective herbicide, or
   - Use tillage to control emerged weeds.
2. **Problem situation:** Need to control weeds that emerge after the crop is planted. Crop residues may absorb or intercept the herbicide, resulting in unsatisfactory weed control.
   Solutions:
   - Select and apply an herbicide or herbicide mixture . . .
     —To control weeds prior to crop emergence, or
     —to control weeds after the crop and weeds have emerged, or
     —in combination with tillage practices to control weeds.
   - Use only essential tillage for weed control.
3. **Problem situation:** Need to control weeds after crop harvest and before the next crop is planted.
   Solutions:
   - Select a contact and/or short residual herbicide that will kill existing weeds. Tillage with sweeps could be used to kill weeds that germinate during the fallow period.
   - Select an herbicide that will control weeds during fallow period. Tillage with sweeps may be used to kill existing weeds.
   - Use only essential tillage to control weeds during the fallow period.

Wheat Diseases

Scientists studying conservation tillage express optimism about fuel savings and erosion control, and pessimism about increased disease and insect problems, and increased use of pesticides.

Not enough research has been done to give a complete answer on wheat diseases, but critical examination is possible through the principles of plant pathology. Continuous cropping would be possible as long as the sequential crops are not susceptible to the same diseases.

Conservation tillage may increase the potential for wheat diseases. But it should not increase plant disease where stubble mulch is pathogen-free or if pesticide control is possible, if a resistant variety is planted, or the environment is not favorable to disease. Growers should use practices that balance the need for erosion control with the need to control plant diseases.

At present, there are no readily usable or thoroughly investigated examples of the use of conservation tillage to reduce disease incidence in wheat. Some studies indicate that residue from a previous nonwheat crop will influence the micro-environment and decrease the development of certain diseases caused by soil-borne organisms. No similar research data are available on the effect of stubble or buried debris in reducing the development of soil-bome or foliar diseases on the following crop of wheat.

Crop sanitation involves eradication of the pathogen by removing or destroying infected crop debris after harvest. However, crop debris cannot be "plowed under" when a double-cropping system is used, where erosion must be controlled, or where water must be conserved. In the future, it may become unlawful to plow down certain areas or burn crop refuse. The effectiveness of these practices in disease control is questionable.

Crop rotations work if they deprive a pathogen of suitable hosts. Their efficiency declines if the pathogen can survive in the soil indefinitely or can be transmitted over long distances by wind or living vectors.

Some Common Wheat Diseases

Cephalosporium stripe of wheat is caused by the fungus **Cephalosporium gramineum.** Its host range is limited, and under Montana conditions it does not infest spring sown wheat, barley, oats, or rye. The fungus lives between hosts (overwinters) in infested stubble, straw, and soil for up to 5 years. Control of the disease is possible by:

1. Delaying seeding in the fall, thus reducing possibility of the disease invading injured roots.
2. Not planting winter wheat in infested areas for 3 years.
3. Destroying all infected straw or stubble.

Wheat streak mosaic virus disease (WSMV) involves a virus transmitted by the wheat curl mite **Aceria tulipae.** Development of WSMV depends mainly on:

1. A high population level of the mites.
2. Nearness of virus-infested plants, especially volunteer wheat or wild grasses, to newly emerged winter or spring wheat.
3. Enough soil moisture to encourage vigorous wheat growth, which also helps mites thrive.
4. Warm fall and spring weather.

Differences occurring in the host vary among strains of the virus and species of closely related mites. Some grasses are hosts for the mites but not the virus, and vice versa. In some states, mites will migrate to corn as winter wheat matures. Thus, corn or spring wheat sown in what were planned to be "fallow strips" may also serve as "bridging hosts" between wheat fields. Neither the wheat curl mite nor the virus can survive longer than a day or two if separated from a living host plant.

Delaying fall planting may allow some fields to escape migrations of virus-bearing mites. In Kansas and Oklahoma, where fields may be planted early for livestock grazing purposes, considerable green tissue is available for bridging, and WSMV is a serious problem in these areas. In Texas, the incidence of WSMV is reduced by a wheat-sorghum-fallow rotation which is apparently sufficient to break the cycle of the mite vector.

To control this virus, destroy all infected or mite-bearing volunteer wheat and host weed grasses in adjoining fields and ditch banks several weeks before planting. Three to four weeks before sowing, destroy them in the fields to be seeded. Since mites are easily blown long distances, in some cases, all farmers in the community should cooperate in destroying stubble and volunteer plants.

Septoria tritici and **S. nodorum** are fungi that cause damage to wheat in the Great Plains. Septoria leaf blotch, caused by **S. tritici,** usually infects fall-sown wheat when the weather is cool and wet. Glume blotch caused by **S. nodorum,** in constrast, is favored by warm, wet weather. In Montana, **S. nodorum** is more prevalent and important than **S. tritici.** The glume blotch phase is rarely found, whereas **S. nodorum** commonly infects leaves and leaf sheaths.

Both fungi overwinter either as mycelium in live wheat plants or as pycnidia on dead plant refuse. They produce an abundance of spores in the early spring. The fungi live through the summer on infected plant debris and on volunteer wheat and then infect new winter wheat seedlings in the fall. **S. nodorum** also infects barley, rye, bluegrass, quackgrass, wild rye and barley, fescues, and other grasses.

Control of these Septoria diseases requires using nonsusceptible crops in rotation, destroying infected stubble as soon as possible after combining, and removing all volunteer plants before seeding. Sowing winter wheat early so that plants will make good growth before cool, moist weather will reduce leaf blotch infection.

In all examples given in the section above:

1. Infected crop debris or volunteer plants are important to survival and spread of the pathogen.
2. No highly resistant varieties can be used in place of rotation to prevent the disease.
3. No fungicides are readily available to kill the pathogen or protect against infection.
4. Heavy levels of infection in localized areas are very sensitive to subtle interactions between host, pathogen

(and vector) and the environment.

Plant pathogens have evolved various mechanisms for survival. Both conservation tillage and continuous cropping can affect these mechanisms.

For a pathogenic plant disease to occur, there must be the right combination of susceptible host plants, a virulent pathogen or causal agent, and a suitable environment. If any one factor is missing, disease will not develop. The wheat variety, weather, and pathogen interactions will vary widely in different locations.

The stubble-mulch and volunteer plants resulting from conservation tillage of wheat will increase plant disease only under the following conditions:

1. A pathogen exists in the previous crop debris (stubble).
2. This pathogen has the ability to survive from one growing season to the next (oversummer or overwinter).
3. A susceptible variety is planted.
4. Environmental conditions favor the establishment and development of disease.

Each disease has unique characteristics and environmental requirements. A new bacterial disease caused by **Pseudomonas syringae,** was observed in wet areas of Montana in 1975. The same wheat variety planted late had less damage than early plantings where flag leaf infections occurred. Yields were reduced by 20 percent on some varieties. More of the disease was found where wheat followed wheat.

Resistant Wheat Varieties

No wheat varieties have been developed specifically for use with conservation tillage under heavy residues. Environment under residues is generally wetter and cooler in spring and summer. It is advisable to consider seedling resistance to foliar and soil-borne diseases when selecting varieties.

Wheat varieties that do well under conventional tillage should be considered for conservation tillage systems. Work is being initiated at several locations in the Great Plains to develop varieties of wheat that will perform well under heavy vegetative residues. Resistant or tolerant germplasms are available and attempts are being made to introduce them into agronomically acceptable varieties for control of **Cepholosporium stripe** (wheat streak mosaic virus), and **Septoria nodorum.** Thus, research offers hope for controlling diseases that plague conservation tillage use.

Insect Problems

Conservation tillage can discourage infestations of some insect pests, and should not materially increase present insect problems.

Insects attack wheat sporadically, when favorable conditions bring outbreaks. Tillage can help control them. Stages of insects such as eggs, larvae or pupae that overwinter can be destroyed by crushing or throwing them to the surface where they are exposed to enemies and unfavorable weather.

Grasshoppers injurious to wheat overwinter in the egg stages and have but one generation per year. Eggs are deposited in pods in the ground. Often ovipositioning female grasshoppers are attracted to weedy habitats, so that eliminating weeds, along with tillage practices that destroy eggs, helps control grasshoppers.

Occasionally, Hessian Fly becomes a problem in winter wheat and causes considerable loss to growers. Using resistant varieties or observing average safe dates for planting will usually keep losses to a minimum. Plowing under infested stubble after harvest, followed by harrowing or turning of soil, will help keep adult flies from emerging.

The Army cutworm, **Euxoa auxiliaris,** occasionally is one of the most destructive species found in the Great Plains. It seems more abundant during dry cycles. This insect overwinters as an immature larva in fields, hatched from eggs deposited in the soil in late September or October.

The pale western cutworm, **Agrostis orthogonia,** is the most destructive. Extensive damage to wheat is linked with less-than-normal amounts of moisture on the Great Plains, and oviposition by this insect occurs primarily in loose soil. One of these cut-

worms per square foot can cause significant loss. The overwintering stage eggs are deposited in the soil in late September or early October. Wheat damage may be minimized by fallow and elimination of weeds. False wireworm, **Eleodes spp.,** are an exception. They are attracted to loose soils that contain much organic matter. **In this situation, conservation tillage practices could encourage development of this pest.** Its normal food is dead or decaying organic matter in the soil, but it does attack growing plants. In most cases insecticide treatment of seed will suffice unless very heavy infestations are present.

Physical-chemical Factors

Soil Structure

More porous soil structure is maintained with stubble mulching than with plowing. This was shown by research in Nebraska, on soil from a corn-oats-wheat rotation that was either continuously subsurface tilled or plowed for a 20-year period.

Soil Temperatures

Wheat residues on the soil surface serve as an insulator between the air and the soil and tend to decrease soil temperature in spring and summer.

At Pendleton, Oregon, studies showed that when temperatures go from summer to winter, the soil under stubble mulch is warmer than bare soil. Soil temperature is a factor when reduced growth is observed with stubble-mulch fallow as compared to bare fallow.

The temperature of soil under mulch is several degrees cooler in the spring and summer, and warmer in the fall and winter than the temperature of unmulched soils. Averaged over the year, there may not be much difference in soil temperature between the two tillage systems.

Stubble mulch on a cool soil delays drying of the soil surface in the spring and may delay planting of some crops. Soil temperature affects nitrification, microbiological activity, nutrient availability, and moisture storage in the soil. Residue management techniques designed to minimize soil temperature depressions and the associated effects are being developed.

Soil Fertility

Conservation tillage returns the plant nutrients in residues to the soil. Larson and Beale found the amounts of these nutrients as shown in table 7 below:

Table 7—**Amounts of nutrients returned to soil from nonharvested or nongrazed stubble**

Crop	Nitrogen	Phosphate (P_2O_5)	Potash (K_2O)
	Pounds per ton		
Corn	18	8	20
Wheat or rye	14	3	23
Oats	12	4	30
Alfalfa	48	11	45

Usually, 100 pounds of straw is produced for each bushel of wheat harvested. A 40-bushel per acre wheat crop would produce 4,000 pounds per acre of straw. This would equal 28 pounds of nitrogen, 6 pounds phosphate, and 46 pounds of potash.

Conservation tillage may cause changes in soil fertility different from those associated with plowing or onewaying. Ammonia production has been reported greater under stubble mulching than with plowing. Ammonia losses during the decomposition of legume residues are higher with sweep tillage than with plowing.

Detailed analyses were made of soil at Lincoln, Nebraska, on both stubble-mulched and plowed plots, with a corn-oats-wheat rotation. These showed that after 20 years, the surface inch of soil on the stubble-mulched plot was higher in total nitrogen, organic matter, amino acids, pH and HCl-soluble and adsorbed phosphorus than the surface inch of soil on the plowed plot. There was no difference due to tillage in the chemical properties of soils on those plots at the 1- to 6-inch depth.

Nitrate content of soil under stubble mulching is generally 5 to 10 percent less than with

plowing or onewaying. Lower nitrate content may occur on some soils as a result of mulch tillage. The amount of nitrate reduction associated with stubble mulching depends on quantity of residue, weather conditions, and other factors.

Reduced nitrogen availability is associated with sweep tillage. This can, in part, be compensated for by applying nitrogen fertilizers or, when moisture is not severely limiting, by using a legume in the rotation. Added nitrogen, however, does not always overcome the yield difference between stubble mulching and other tillage practices. Research is needed on the nitrogen balance of soils with stubble-mulch tillage.

Fertilizers

For nonirrigated winter wheat, one fertilizer guide recommends: "When seeding in straw mulch, increase nitrogen rate by 10 pounds per acre for each 1,000 pounds per acre of mulch on the soil surface. This is in addition to the normal nitrogen recommendation."

Reasonably accurate nitrogen recommendations can be made if the soil moisture and nitrate levels can be determined, and extra straw decomposition is considered. Nitrogen recommendations change when producers shift from conventional to continuous cropping or to a different cropping sequence.

Dryland winter wheat yields are often increased by nitrogen fertilizers in addition to the small amount of nitrogen applied at or before seeding. Keys to success of this practice are as follows:

1. The phosphorus and other nutrient needs must be met. Phosphorus (and potassium) should be applied at the time of seeding, or before, and according to soil tests.
2. Soil nitrate amounts will influence the need for more nitrogen fertilizer. Testing deep samples will markedly improve the chances for correctly assessing nitrogen needs. Correct sampling and handling of the samples are extremely important for the nitrate test.
3. Know your available water supply, or at least the probability of its being adequate. Take deep soil samples to 4 feet or more (which is the major part of the root zone). Consider past records of precipitation during the growing season in your area. Use all this data to determine how much nitrogen to put on the field.
4. Do operations on time. If nitrogen fertilizers are top-dressed on wheat in late spring, they may not be efficiently utilized for the current crop.
5. Remember to consider all factors affecting crop yield and quality. The more of these that are measured, the better can be the predictions for profitable use of nitrogen.

Nutrient Content of Plants

Data collected in Nebraska show that the nitrogen content of corn, oats, and wheat plants and grain was slightly lower with stubble mulching than with plowing. The amounts of phosphorus, potassium, calcium, and magnesium in corn, oats, and wheat grain were not affected by the two tillage systems. These results have been confirmed at other locations. Throughout the Great Plains and in the Pacific Northwest, protein content of grain, in general, is slightly lower with stubble mulching than with plowing. There is no evidence that any lowering of the milling and baking quality of grain is attributable to mulch farming.

Microorganisms

Bacteria, actinomycetes, fungi, denitrifiers, earthworms, and nematodes are more numerous in the surface inch of stubble-mulch soil than in plowed soil. Greater microbial activity in the surface inch of soil, therefore, may account in part for changes in nitrification and yields obtained with stubble mulching. Nearly all soil microorganisms, such as fungi, bacteria, and actinomycetes, are active in the decomposition of crop residues. Research is being conducted on use of decomposition inhibitors in areas where it is desirable to preserve more crop residues.

Residue Management

Crop residues decompose more slowly when

left on the surface of the soil than when plowed under. Nevertheless, in some areas, such as the southern Great Plains, crop residue may decompose so rapidly that it is difficult to maintain protective soil cover. In cooler and drier areas, residues decompose more slowly, and it may be desirable to work some residues into the soil to hasten their decomposition. Where decomposition is too rapid, a minimum of tillage is recommended to preserve the residues and protect the soil against erosion by wind or water. Use of chemicals in lieu of tillage to kill weeds will help preserve residues.

Plant-growth Inhibitors

In some instances, the crop yield reductions encountered with stubble mulching may be due to plant-growth inhibitors produced by soil microorganisms during decomposition of the crop residues used as mulch.

Apparently, phytotoxic substances of many different types are produced by a myriad of microorganisms and higher plants. This is important ecologically, since naturally occurring phytotoxic substances from higher plants and microorganisms also affect plant and microbial ecology.

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